Abstract

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Field experiments were conducted from 1984 through 1991 to determine the agronomic and economic effect of irrigation on monocultures of corn [*Zea mays* (L.)], sorghum [*Sorghum bicolor* (L.) Moench], and soybean [*Glycine max* (L.) Merr.] on Tunica clay soil (Vertic Haplaquept) in the Mississippi Delta. Irrigation increased the average yield of corn and soybean 92 percent and sorghum 18 percent over the 8-year test period. Although seed yields of crops are often used to assess the values and relationships of various cropping practices, economic returns must ultimately be considered the deciding factor when establishing long-term cropping practices. The cropping systems with the highest average net returns per acre (in descending order) were irrigated corn ($79.48), nonirrigated sorghum ($59.87), and irrigated soybean ($52.85). Average net returns of irrigated sorghum, nonirrigated corn, and nonirrigated soybean were $19.01, –$9.44, and $24.73 per acre, respectively, and were not sufficient to cover land charges. These data indicate that irrigation increased the average net returns of corn and soybean but not sorghum.

Keywords: economic analysis, cropping system, yields, crop rotation, irrigation, corn, sorghum, soybean, monocrop, doublecrop.

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Effects of Irrigation on Corn, Sorghum, and Soybean in the Mississippi River Alluvial Plain

An Economic Analysis

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The Mississippi River alluvial flood plain contains approximately 9.6 million acres of clayey soils. Virtually all of this acreage is in crop production. The greatest percentage of the cropped acreage is used for monocultures of soybean [*Glycine max* (L.) Merr.] and is not irrigated. Soybean yields from this system of production have been consistently low (Heatherly 1983, Heatherly 1988, Wesley and Cooke 1988, Heatherly et al. 1990). Sorghum [*Sorghum bicolor* (L.) Moench] and rice [*Oryza sativa* L.] are also planted on these soils but to a lesser extent. The climate of this region is also suitable for corn [*Zea mays* L.] production; however, it is produced on few acres of the shrink-swell clays, which are typical of the area.

The responses of corn, sorghum, and soybean to irrigation and the proper timing of irrigation are well documented by Rhoads and Bennett (1990) for corn, Sweeten and Jordan (1987) for sorghum, and Heatherly (1985) and Reicosky and Heatherly (1990) for soybean. All crops have the capability to produce higher yields with properly timed irrigation under drought conditions.

An economic analysis of irrigation effects on soybean grown on Dubbs silt loam (Typic Hapludalf, fine-silty, mixed, thermic) and Sharkey clay (Vertic Haplaquept, very fine, montmorillonitic, thermic) in the Mississippi Delta indicated that properly timed irrigation of soybean can result in increased returns to help offset overhead from land rental, management, and general farm costs (Salassi et al. 1984). Conversely, returns of nonirrigated soybean monocrops grown on Tunica clay (clayey over loamy, montmorillonitic, nonacid, thermic Vertic Haplaquept) were not sufficient to cover land rental charges (Wesley and Cooke 1988). Sanford et al. (1986) conducted a study of nonirrigated crops grown on Leeper silty clay (fine montmorillonitic, nonacid, thermic Vertic Haplaquept) to evaluate monocrop systems of corn, soybean, sorghum, wheat [*Triticum aestivum* L.], and sunflower [*Helianthus annuus* L.] and doublecrop systems of wheat rotated with corn, sorghum, soybean, and sunflower. The highest net return was produced by monocrops of corn followed closely by a doublecrop of wheat-soybean. Wesley et al. (1994) compared yields and economic returns to soybean monocrops, wheat-soybean doublecrops, and 2-year rotations of corn/wheat-soybean and sorghum/wheat-soybean on Tunica clay in Mississippi. The wheat-soybean doublecrop system produced one of the highest average net returns in both irrigated (I) and nonirrigated (NI) environments, whereas the soybean monocrop system produced one of the lowest net returns in both environments. Crabtree et al. (1986) compared yields and net returns of monocrops and doublecrops of wheat and sorghum on a Wynona silt loam soil (Cumulic Haplaquolls) in Oklahoma; the wheat was grown only under NI conditions, and the sorghum was grown under both NI and I conditions. NI wheat monocrops produced the highest net returns, but the net returns of the NI sorghum monocrops and NI wheat doublecropped with I sorghum were almost as high.

Crop yields are often used to determine the value and make comparisons of various cropping systems. However, net returns must ultimately be considered and probably should be the dominant factor considered in making comparisons. Cropping systems must be profitable before they are recommended for long-term use by producers. The objectives of this study were to simultaneously conduct long-term field evaluations of monocultures of corn, sorghum, and soybean on a shrink-swell clay soil to (1) determine yield response of each crop in I and NI environments and (2) determine

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and compare economic returns of each cropping system. The second objective is emphasized in the "Results and Discussion" section.

Materials and Methods

General Materials and Procedures

The study was conducted from 1984 through 1991 on a Tunica clay near Stoneville, MS. Two adjacent areas were designated for the experiment—one for I production and one for NI production. Plots of each crop were 40 feet wide (twelve 40-inch-wide rows) and 100 feet long in a randomized complete block design with four replicates in both the I and NI experiments. The center two (corn) or four rows (sorghum and soybean) of each plot were harvested for seed yield.

The area was disk-harrowed twice on October 18, 1984. Corn and sorghum plots were bedded, whereas soybean plots remained flat. All plots were mechanically cultivated for weed control as needed during the early part of each growing season. All N applications to corn and sorghum were applied beside each row as urea-NH_4NO_3 solution. Fertilizers were applied at recommended rates, whereas all pesticides were applied at the labeled rates as dictated by the prevailing conditions each year of the study.

In 1984 furrow irrigation was initially used because of a delay in installation of an overhead lateral-move system. In succeeding years, however, only the overhead system was used. Each crop in each replicate was irrigated separately by controlling gates and nozzles. Irrigation of corn began at tassel emergence and ended at near-dent stage. Irrigation of sorghum began at boot stage and ended at the hard-dough stage. Soybean irrigation started when the first bloom appeared and ended at the full-seed stage.

For corn, sorghum, and soybean, water deficits that occur during reproductive stages are most detrimental to final grain or seed yield (Heatherly 1985, Sweeten and Jordon 1987, Reicosky and Heatherly 1990, and Rhoads and Bennett 1990); therefore, irrigation water was applied in this study only during each crop's reproductive period. Irrigation was performed whenever soil water potential (as determined by tensiometers located at the 12-inch soil depth in three replicates) averaged between –50 and –70 centibars. Previous research with soybean on clay soil showed that a greater yield response was obtained when the need for irrigation was measured at this depth rather than a deeper depth (Heatherly 1984).

All crops were machine harvested at maturity. Plot weights and seed yield data for corn, sorghum, and soybean were adjusted to a seed moisture content of 15.5, 14.0, and 13.0 percent (dry weight), respectively, and were analyzed separately for each year and irrigation regime. Specific agronomic inputs to each crop grown in the I and NI studies are given in Heatherly et al. (1990).

The power complement included one 90- to 100-drawbar-horsepower (DBHP) tractor, one 100- to 115-DBHP tractor, one 115- to 150-DBHP tractor, and one self-propelled combine having a 20-foot header width, reel equipment, and an auxiliary header for harvesting corn. The other equipment included a heavy disk, disk harrow, field cultivator, no-till planter, cultipacker, cultivator, liquid-fertilizer applicator, stalk shredder, spin spreader, and tractor-mounted sprayer.

Determination of Costs and Returns

Crop enterprise budgets were developed for each annual cycle of each cropping system in the I and NI environments. The cost of all variable inputs such as fertilizers, pesticides, and irrigation water were based on the actual inputs used for crop production in the experiments. Crop prices used in the budgets were the seasonal average prices received for the year as reported by the Mississippi Agricultural Statistics Service (1984–91) and adjusted for deficiency payments per unit of corn and sorghum. Variable costs were also based on prices paid by farmers each year and included the cost of herbicides, seed, labor, fuel, equipment repairs and maintenance, and interest on operating capital. Fixed costs included costs of tractors, self-propelled equipment, implements, and the irrigation system. Total specified costs included both variable and fixed costs. Net returns per acre were calculated as the difference between gross income and

total specified costs. The average net returns for each crop were calculated over the 8-year study period. In constructing the budgets, no charges were included for land, management, or overhead. Performance rates on all field operations were based on using eight-row equipment with associated power units.

Irrigation costs were based on a quarter-mile center pivot system capable of irrigating 130 acres from 1 pivot point. Investment costs included the cost of an engine, well, pump, gearhead, generator, fuel tank and fuel lines, and the pivot system. Total fixed costs consisted of annual depreciation, interest on investment, and insurance. Annual depreciation was calculated using the straight-line method with zero salvage value. Annual interest charges were based on one-half of the original investment times the nominal interest rate for each year of the study. Insurance cost was estimated at 1 percent of the original investment. Operating or direct costs included fuel, oil, labor, and engine repair. Fuel requirements were determined from engineering formulas (Spurlock et al. 1987).

Results and Discussion

Yields, commodity prices, gross returns, total specified costs, and net returns above total specified costs are presented in tables 1–5 for each cropping system in the I and NI environments. The average fixed and variable costs associated with each cropping system and the range in costs of the selected components are shown in table 6.

Effects of Irrigation on Crop Yield

Yields of all crops produced during the first 4 years of this study (1984–87) are discussed in detail in Heatherly et al. (1990). Yields of I corn, I sorghum, and I soybean produced during crop years 1988–91 were generally typical of yields produced during crop years 1984–87. Over the 8-year test period, irrigation increased the yield of corn in all years, increased the yield of sorghum in 1984, 1985, 1987, and 1988, and increased the yield of soybean in all years except in 1989 and 1991 (table 1).

Over the 8-year study, irrigation increased corn and soybean yields 92 percent but increased sorghum yield only 18 percent. In the NI studies, two notable yield abnormalities occurred during crop years 1988–91. First, in 1988 extremely dry conditions occurred from mid-April through mid-July. Corn plots were bedded, planted, and fertilized in a timely manner, and corn emerged but died later due to insufficient soil moisture. All NI sorghum plots were bedded and fertilized with 80 pounds N/acre but were not planted due to insufficient soil moisture for emergence. No soybean plots were planted. However, in retrospect, sorghum and soybean could have been planted in 1988 following rain in mid-July, but at the time this did not appear feasible. The zero yields in 1988 severely reduced the average yield of each NI crop over the 8-year test period. Second, the yields of NI soybean in 1989 and 1991 were considerably higher than all other yields of NI soybean during the test period. These high yields were attributed to timely rainfall events during the reproductive periods.

Economic Returns in Response to Irrigation

Gross returns per acre (table 3) were calculated as the product of each respective crop yield (table 1) and commodity price (table 2). In 1988, when severe drought prevented the planting and development of all crops in the NI environment, gross returns for the NI crops were zero and thus abnormally decreased the average gross returns and net returns (table 5) for the NI crops over the 8-year period.

Corn. Total specified costs of production for corn in the I study ranged from $218.50/acre to $318.50/acre over the 8-year period, and in the NI study specified costs of corn production ranged from $145.10/acre to $242.63/acre (table 4). The high costs in 1985 in the I and NI environments were partially due to an outbreak of yellow nutsedge (*Cyperus esculentus*) and the subsequent application of bentazon that increased specified costs by $19.80/acre. In 1989 the high specified costs for corn in the I and NI studies were caused by the broadcast application of dicamba to control perennial vines, thereby increasing production costs by $30.22/acre. In 1988 the specified costs of I corn were fairly high, but the costs of NI corn were lower because it was not harvested.

The total specified costs of production for I and NI corn over the 8-year test period averaged $259.63/acre and $180.32/acre, respectively. The difference in the costs of producing I and NI corn was mainly attributed to the higher cost per acre for fuel ($9.34), labor ($2.12), fertilizer ($3.19), and irrigation equipment ($51.26) (table 6). Herbicide costs of I and NI corn were identical throughout the test period. The highest herbicide cost per acre ($63.03) was recorded in 1989 and resulted from the application of dicamba ($30.22) for perennial vine control and quizalofop ($15.38) for johnsongrass control.

Irrigation increased the net returns of corn each year except in 1987 (table 5) when the yield of NI corn averaged 80 percent of the yield of I corn (table 1). The high net returns of I corn in 1984 were attributed to the exceptional price ($3.42/bushel, table 2), whereas in 1985 and 1990 the high net returns resulted from corn yields that averaged 140.5 and 144.1 bushels/acre, respectively (table 1). Average net returns (table 5) of NI corn over the 8-year period ranged from highly negative in 1988 (–$155.12/acre), when the corn died and was not harvested, to moderately positive in 1987 ($64.80/acre). For the 8-year study, the average net returns of I corn were positive ($79.48/acre), whereas average net returns of NI corn were negative (–$9.44/acre).

Sorghum. Total specified costs of production for sorghum in the I study ranged from $203.96/acre to $270.05/acre, whereas in the NI study these costs ranged from $36.92/acre (crop not planted) to $209.30/acre (table 4). Specified costs of production for I sorghum in 1988 were somewhat higher than in all previous years due to an application of glyphosate after sorghum harvest in 1987 for johnsongrass (*Sorghum halepense* L.) control and at planting in 1988 for burnback and control of johnsongrass. These glyphosate applications and the annual application of atrazine and metolachlor failed to adequately control johnsongrass in the I and NI sorghum plots. Therefore, quizalofop was applied after harvest of the I study in 1988, and an application of glyphosate was made to both studies prior to planting in 1989. Use of these two herbicides in the I and NI sorghum plots increased the specified costs of production in 1989. At present, johnsongrass levels in all plots remain high, sorghum yield levels have decreased, and costs for herbicides to control johnsongrass are too high to justify further plantings.

Over the study period, the total specified costs for I and NI sorghum averaged $238.71/acre and $152.04/acre, respectively. The higher costs of producing I sorghum were attributed to higher costs of fuel ($10.95), labor ($4.19), herbicides ($4.48), and the irrigation system ($53.30). High herbicide costs in 1988 and 1989 were attributed to the use of aforementioned herbicides for johnsongrass control. The combination of high herbicide cost and the failure to achieve control of johnsongrass in sorghum indicates that this cropping system may become too risky for long-term consideration.

During the 8-year study, net returns of I sorghum were smaller and more variable than the net returns of NI sorghum (table 5). Net returns of I sorghum ranged from –$89.38/acre in 1986 to $110.38/acre in 1988. Net returns of NI sorghum ranged from –$36.92/acre in 1988, when the crop was not planted, to $107.50/acre in 1989. Irrigation slightly increased yields of sorghum in 1984, 1985, and 1987 and dramatically increased yields in 1988 (table 1); however, net returns of I sorghum exceeded returns from NI sorghum only in 1988 when NI sorghum was not planted. In fact, sizable net losses resulted from the irrigation of sorghum in 1986 (–$89.38/acre) and 1991 (–$66.49/acre). Over the 8-year test period the average net returns of NI sorghum ($59.87/acre) were more than three times higher than returns of I sorghum ($19.01/acre). Obviously, the cost of irrigating sorghum was not offset by profitable yield increases from the irrigation. Also, yields of NI sorghum exceeded the yields of I sorghum in 1986, 1989, 1990, and 1991 and were within 10 percent of the yields of I sorghum in all other years except in 1988.

Soybean. Over the 8-year period specified costs of production for I soybean ($192.85/acre) were almost twice the average specified costs for producing NI soybean ($99.05/acre) (table 4). The difference in the

costs of producing I and NI soybean was attributed to the difference in the cost per acre for fuel ($15.27), labor ($3.64), herbicides ($5.09), and the irrigation system ($52.99) (table 6). The abnormally low herbicide cost of $10.95/acre resulted from an application of glyphosate in 1988 prior to anticipated planting. However, because of drought, soybean was not planted in the NI study and no other inputs were needed. The high herbicide costs in both the I and NI studies were attributed to the use of preemergence and postemergence broadleaf and grass materials that were broadcast.

Net returns of I soybean ranged from a low of –$58.08/acre in 1986 to a high of $161.32/acre in 1988 (table 5). Over the 8-year test period net returns of I soybean monocrops were positive ($52.85/acre). Net returns of NI soybean monocrops were either negative or near zero in 5 of the 8 years. The yields of NI soybean were exceptionally high in 1989 (49.8 bushels/acre) and 1991 (40.8 bushels/acre) (table 1) and thus contributed to exceptionally high net returns of $176.98/acre and $117.57/acre, respectively (table 5). However, the average net return of NI soybean was only $24.73/acre over the 8-year test period. This net return was not sufficient to cover land rental charges. Obviously, banded applications of all preemergence and postemergence herbicides would have increased net returns of soybean in these studies and should be considered as a cost reduction method in any soybean production system in which postemergence cultivation is also used for weed control.

Justification for Irrigation

Crop irrigation is recommended only when it leads to a profit. Net returns must be used to determine whether or not to irrigate a particular crop. In this study irrigation of corn proved to be profitable. Corn had the highest and most consistent net returns. Irrigation of corn increased yields an average of 92 percent (55.9 bushels/acre) and produced positive net returns each year except in 1991 when small but negative returns resulted. Yields of NI corn averaged only 60.9 bushels/acre and thus resulted in negative net returns (–$9.44/acre) over the study period.

Irrigation of sorghum increased seed yields in 4 of the 8 years, but was economically advantageous only in 1988 when severe drought prevented planting of sorghum in the NI study. Irrigation increased the average yield of sorghum 18 percent (14.1 bushels/acre); however, these yield increases were not sufficient to cover irrigation costs. Therefore, average net returns of NI sorghum ($59.87/acre) were 3.2 times higher than net returns of I sorghum ($19.01/acre).

Yields of I soybean were greater than yields of NI soybean in all years except in 1989 and 1991 when exceptionally high yields of NI soybean were produced. Over the 8-year study period irrigation increased the average yield of soybean 92 percent (19.6 bushels/acre). Net returns of I soybean were positive in all years except in 1986 when yields of I soybean averaged only 30.5 bushels/acre. Average net returns of I soybean monocrops were $52.85/acre. Yields of NI soybean were highly variable and averaged only 21.5 bushels/acre over the study period. Net returns of NI soybean were virtually zero or negative in 5 of the 8 years. The average net returns of NI soybean ($24.73/acre) were not sufficient to cover land charges.

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Table 1. Yields of corn, sorghum, and soybean monocultures grown on Tunica clay near Stoneville, MS

Crop year	Corn		Sorghum		Soybean	
	I*	NI*	I	NI	I	NI
	bushels/acre					
1984	97.0	44.0	111.0	95.0	38.2	12.6
1985	140.5	78.6	116.5	109.3	37.8	23.5
1986	128.6	82.0	52.8	62.1	30.5	1.6
1987	112.4	89.8	109.7	99.1	45.6	20.8
1988	95.6	0.0†	106.9	0.0†	48.9	0.0†
1989	124.6	92.1	90.6	96.0	47.0	49.8
1990	144.1	55.2	89.1	94.3	42.3	22.9
1991	91.3	45.1	74.0	82.9	38.7	40.8
Average	116.8	60.9	93.9	79.8	41.1	21.5

**I* = irrigated during reproductive development and *NI* = nonirrigated.

†Corn emerged but died; sorghum and soybean were not planted due to lack of soil moisture for germination.

Table 2. Seasonal average price of soybean and seasonal average prices plus deficiency payment received for corn and sorghum in Mississippi

Crop year	Commodity price		
	Corn	Sorghum	Soybean
	dollars/bushel		
1984	3.42	2.53	6.10
1985	2.97	2.24	5.20
1986	2.30	2.17	5.10
1987	2.64	2.66	5.84
1988	3.48	3.35	7.50
1989	2.98	3.30	5.90
1990	2.92	2.98	5.90
1991	2.70	2.58	5.70

Source: Mississippi Agricultural Statistics Service (1984–1991).

Table 3. Gross returns of corn, sorghum, and soybean monocultures grown on Tunica clay near Stoneville, MS

Crop year	Corn		Sorghum		Soybean	
	I*	NI*	I	NI	I	NI
	dollars/acre					
1984	331.74	150.48	280.83	240.35	233.02	76.86
1985	417.29	233.44	260.96	244.83	196.56	122.20
1986	295.78	188.60	114.58	134.76	155.55	8.16
1987	296.74	237.07	291.80	263.61	266.30	121.47
1988	332.69	0.0†	358.11	0.0†	366.75	0.0†
1989	371.31	274.46	298.98	316.80	277.30	293.82
1990	420.77	161.18	265.52	281.01	249.57	135.11
1991	246.51	121.77	190.92	213.88	220.59	232.56
Average	339.10	170.88	257.71	211.91	245.71	123.77

**I* = irrigated during reproductive development and *NI* = nonirrigated.
†Gross incomes were zero because crops were not harvested.

Table 4. Total specified costs of production of corn, sorghum, and soybean monocultures grown on Tunica clay near Stoneville, MS

Crop year	Corn		Sorghum		Soybean	
	I*	NI*	I	NI	I	NI
	dollars/acre					
1984	218.50	145.10	230.78	162.48	186.64	111.69
1985	274.14	190.84	228.49	151.03	193.04	116.55
1986	234.88	172.83	203.96	148.98	213.63	95.63
1987	234.47	172.27	221.94	157.62	196.36	117.85
1988	273.51	155.12†	247.73	36.92†	205.43	14.77†
1989	318.50	242.63	270.05	209.30	188.65	116.84
1990	264.25	181.39	249.28	188.22	177.77	104.04
1991	258.75	182.35	257.41	161.73	181.31	114.99
Average	259.63	180.32	238.71	152.04	192.85	99.05

**I* = irrigated during reproductive development and *NI* = nonirrigated.
†Production inputs and costs for corn were normal; however, corn yield was zero. Production costs for sorghum and soybean were minimal because crops were not planted.

Table 5. Net returns above specified costs for corn, sorghum, and soybean monocultures grown on Tunica clay near Stoneville, MS

Crop year	Corn		Sorghum		Soybean	
	I *	NI*	I	NI	I	NI
	dollars/acre					
1984	113.24	5.38	50.05	77.87	46.38	–34.83
1985	143.15	42.60	32.47	93.80	3.52	5.65
1986	60.90	15.77	–89.38	–14.23	–58.08	–87.47
1987	62.27	64.80	69.86	105.98	69.94	3.62
1988	59.18	–155.12†	110.38	–36.92†	161.32	–14.77†
1989	52.81	31.83	28.93	107.50	88.65	176.98
1990	156.52	–20.21	16.24	92.79	71.80	31.07
1991	–12.24	–60.58	–66.49	52.15	39.28	117.57
Average	79.48	–9.44	19.01	59.87	52.85	24.73

**I* = irrigated during reproductive development and *NI* = nonirrigated.
†Crops were not harvested.

Table 6. Average variable costs, fixed expenses, and total costs of corn, sorghum, and soybean monocultures grown on Tunica clay near Stoneville, MS

Cropping system*	Variable costs										Fixed expense§		Total Cost
	Fuel		Labor		Herbicides		Fertilizer		All other‡				
	Mean†	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
	dollars/acre												
Corn													
CC–I	16.56	9.42–25.91	22.07	13.90–28.39	27.54	14.89–63.03	38.66	29.75–52.73	70.06	52.42–84.39	87.46	79.89–100.23	262.34
CC–NI	7.22	5.76–8.83	19.95	12.77–23.56	27.54	14.89–63.03	35.47	27.55–52.73	56.64	40.54–69.03	36.20	16.90–46.24	183.03
Sorghum													
SGSG–I	18.34	11.84–27.03	24.68	18.86–29.34	29.72	18.43–47.60	31.80	28.65–37.65	50.11	35.29–62.67	85.16	77.72–94.92	239.81
SGSG–NI	7.39	2.36–11.13	20.49	8.61–28.18	25.24	14.51–47.60	27.47	0.00–37.65	40.82	5.45–51.71	31.86	6.16–43.29	153.28
Soybean													
SBSB–I	20.52	13.99–24.51	15.53	14.30–16.95	34.78	26.22–46.45			44.00	35.84–59.55	78.02	71.16–88.08	192.85
SBSB–NI	5.25	0.41–7.79	11.89	1.37–15.30	29.69	10.95–42.39			27.20	1.14–36.11	25.03	0.90–31.97	99.05

*Cropping systems: *CC* = continuous corn monocrop, *SGSG* = continuous sorghum monocrop, and *SBSB* = continuous soybean monocrop; *I* = irrigated and *NI* = nonirrigated.
†Means for all categories represent the 8-year average. Means for all NI variables include the lower-than-normal production costs of 1988 when the crops were not harvested.
‡All other expenses include costs of seed, insecticides, repairs and maintenance, interest on operating capital, and hauling costs.
§Fixed expenses include costs of tractors, self-propelled equipment, implements, and the irrigation system.